IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Patent Application of	Date: Dec. 18, 2009
Applicants: Bednorz et al.	Docket: YO987074BZ
Serial No.: 08/479,810	Group Art Unit: 1751
Filed: June 7, 1995	Examiner: M. Kopec
Appeal No. 2009-003320	

For: NEW SUPERCONDUCTIVE COMPOUNDS HAVING HIGH TRANSITION TEMPERATURE, METHODS FOR THEIR USE AND PREPARATION

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SUPPLEMENT 2
REQUEST FOR REHEQRING
UNDER
37 C.F.R. § 41.52 (a)(1)
Of
Decision on Appeal dated 09/17/2009

ATTACHMENTS

Please charge any fee necessary to enter this paper and any previous paper to deposit account 09-0468.

Respectfully submitted,

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ATTACHMENT BP

IN RE GORDON HENRY COOK AND PETER ARNOLD MERIGOLD

No. 8446

United States Court of Customs and Patent Appeals

58 C.C.P.A. 1049; 439 F.2d 730; 1971 CCPA LEXIS 376; 169 U.S.P.Q. (BNA) 298

Oral argument February 3, 1971
April 8, 1971 *

* Petition for rehearing July 1, 1971.

PRIOR HISTORY: [***1] APPEAL from Patent Office, Serial No. 309,208

DISPOSITION: Affirmed.

CASE SUMMARY:

PROCEDURAL POSTURE: Appellants sought judicial review of an examiner's decision which was affirmed by the Patent Office Board of Appeals, which denied their application for a patent for a type of zoom lens because they failed to meet the specification requirements of *35 U.S.C.S. § 112*.

OVERVIEW: Appellants were denied a patent for zoom lens designs because under *35 U.S.C.S. § 112*, appellants' disclosure was not sufficiently specific and would require many months to be carried out by a skilled designer. The examiner also found that appellants' six examples were not representative of the ranges recited in the claims and appellants had failed to give a satisfactory explanation of the origin of the range limitations. The court found the first argument without merit because appellants' disclosure was specific enough to teach those skilled in the art how to design a new zoom lens without undue effort. Regarding the second argument, the court found that appellants had failed to prove that there were embodiments to be found throughout the broader claimed ranges, and therefore the requirement of *§ 112* that the specifications be true and enabling had not been met.

OUTCOME: Denial of appellants' patent application was affirmed because appellants failed to show that the teachings embodied in

their specifications for a new type of zoom lens were both true and enabling.

CORE TERMS: lens, inoperative, zoom, embodiment, examiner, patent, specification, assembly, lense, zoom lens, disclosure, parameters, species, focal length, broad claims, zooming, skilled, divergent, variation, movable, piston, valves, chemical, optical, invention, designer, numerically, subject matter, time-consuming, satisfactory

LexisNexis(R) Headnotes

Patent Law > Claims & Specifications > Description Requirement > General Overview
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals
[HN1] Patent claims may be too broad to the point of invalidity by reason of reading on significant numbers of inoperative embodiments.

Patent Law > Claims & Specifications > Description Requirement > General Overview
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals
[HN2] The court sees no reason why the Patent Office as well as the courts deciding infringement litigation should not have authority to reject a broad claim merely because it reads on a significant number of inoperative species.

Patent Law > Claims & Specifications > Description Requirement > General Overview
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals
[HN3] While the court has held that the mere possibility of inclusion of inoperative subject matter does not prevent allowance of broad claims, when the examiner sets forth reasonable grounds in support of his conclusion that an applicant's claims may read on inoperative subject matter, it becomes incumbent upon the applicant either to reasonably limit his claims to the approximate area where operativeness has not been challenged or to rebut the examiner's challenge either by the submission of representative evidence or by persuasive arguments based on known laws of physics and chemistry.

Patent Law > Claims & Specifications > Enablement Requirement > General Overview
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals
Patent Law > Nonobviousness > Elements & Tests > Ordinary Skill Standard
[HN4] Many patented claims read on vast numbers of inoperative embodiments in the trivial sense that they can and do omit factors which must be presumed to be within the level of ordinary skill in the art, and therefore read on embodiments in which such factors may be included in such a manner as to make the embodiments inoperative. There is nothing wrong with this so long as it would be obvious to one of ordinary skill in the relevant art how to include those factors in such manner as to make the embodiment operative rather than inoperative.

Patent Law > Claims & Specifications > Description Requirement > General Overview
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals
[HN5] The word "obvious" under *35 U.S.C.S. § 112* means that those skilled in the art would know how to determine utility without having to build and try out the conceived embodiment and could do so without the expenditure of unreasonable effort.

Patent Law > Claims & Specifications > Description Requirement > General Overview
Patent Law > Jurisdiction & Review > Subject Matter Jurisdiction > Appeals

Patent Law > U.S. Patent & Trademark Office Proceedings > Appeals
[HN6] *35 U.S.C.S. § 112* requires not that the specifications merely say how to use the claimed invention, but that such teaching be true, i.e., in fact enabling.

COUNSEL: *Holcombe, Wetherill & Brisebois,* attorneys of record, for appellant.

Joseph F. Brisebois, John A. Feketis, of counsel.

S. Wm. Cochran for the Commissioner of Patents. *R. V. Lupo,* of counsel.

OPINION BY: RICH

OPINION

[**730] [*1049] Before RICH, ALMOND, BALDWIN, LANE, Associate Judges, and FORD, Judge, sitting by designation

RICH, Judge, delivered the opinion of the court.

[*1050] This appeal is from the decision of the Patent Office Board of Appeals affirming the examiner's rejection of claims 1-27 in appellants' application serial No. 309,208, filed September 16, 1963, for "Optical Objectives of Variable Equivalent Focal Length Having Two Divergent [**731] Members For Zooming Purposes." We affirm.

The Invention

The rejected claims are for an allegedly improved version of a particular kind of "optical objective of the 'zoom' type." In common parlance, an optical objective is called a lens. A "zoom" lens assembly is one in which the focal length, and consequently the image size as seen from a fixed position, can be varied continuously by movement of certain lens elements [***2] to vary the scale of the image without loss of focus. The zoom lenses involved here have four optical members, the outer one of which is axially movable for focusing purposes but stationary during zooming, the middle two of which are axially movable to produce the zooming effect, and the innermost one of which is stationary. Such lens assemblies are extremely complex from the optical design standpoint; the six examples set forth in appellant's specification are each characterized by over one hundred related parameters. The rejected claims recite certain relationships among a relatively small number of these parameters, the stated purpose of which is to extend the range over which the scale of the image provided by the lens assembly, i.e., the equivalent focal length, can be varied without experiencing an unacceptably high degree of image distortion at any point in the range. [1]

1 According to appellants' brief, "designers have been heretofore unable to design a lens having both adequate correctional properties and a zooming range in excess of about six times its minimum focal length." Appellants' examples, the operativeness of which has not been challenged, are of lens assemblies in which the zooming range is ten to one.There is no evidence in the record to support the assertion that a range of over six to one has not heretofore been possible, but whether or not it is true is unimportant. No prior art being relied on, appellants had no need of recourse to objective indicia of nonobviousness. Whether or not their application teaches how to make a better zoom lense is irrelevant to the issue before us.

[***3] Claim 1 is illustrative (subparagraphing and emphasis supplied):

1. An optical objective of the zoom type (that is of the type having relatively movable members whereby the equivalent focal length of the objective can be continuously varied throughout a range, whilst maintaining constant position of the image plane), corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and

comprising

a convergent first member which for a given object distance remains stationary during the zooming relative movements,

an axially movable divergent second member behind the first member having equivalent focal length fb lying numerically between 4 and 8 times the minimum value of the ratio of the equivalent focal length of

[*1051] the complete objective to the f-number of the objective in the range of variation,

an axially movable divergent third member behind the second member having equivalent focal length f(c) lying numerically between 5 and 10 times the minimum value of such ratio,

a stationary convergent fourth member behind the third member,

a zoom control element, and

means whereby operation of the zoom control element causes [***4] the zooming relative movements to be effected,

wherein

the total axial movement of the second member in the range of variation lies numerically between 1.5f(B) and 2.5f(B) and

the total axial movement of the third member in the range lies numerically between 0.25(c) and 0.5f(C),

[**732] the minimum axial separation between the second and third members occurring when the equivalent focal length of the objective is greater than half its maximum value in the range of variation,

the movable divergent second member consisting of a divergent simple meniscus component with its surfaces convex to the front and a divergent compound component behind such simple component, and

the movable divergent third member consisting of a doublet component having its front surface concave to the front with radius of curvature lying numerically between 0.5f(C) and 1.0f(C).

The Rejection

There is no rejection on prior art. The examiner rejected all of appellants' claims under both the first and second paragraphs of *35 USC 112*. The board affirmed both rejections. However, at oral argument the solicitor for the Patent Office, noting that the rejections on the second paragraph of *§ 112* [***5] were "prior to the court's decisions in Robins [*In re Robins, 57 CCPA 1321, 429 F.2d 452, 166 USPQ 552 (1970)*] and predecessor cases [presumably, *In re Borkowski, 57 CCPA 946, 422 F.2d 904, 164 USPQ 642 (1970)*, *In re Halleck, 57 CCPA 954, 422 F.2d 911, 164 USPQ 647 (1970)*, and *In re Wakefield, 57 CCPA 959, 422 F.2d 897, 164 USPQ 636 (1970)*]," stated that "Today we may consider the Office's position * * * under paragraph one completely." In view of this statement, we reverse the rejection under the second paragraph of *35 USC 112* on the basis of the above-cited cases.

Two distinct rationales are apparent in the rejection below under the first paragraph of *§ 112*. First, appellants' disclosure was said to be insufficient because it would require many months for a skilled lens designer, working with the aid of a computer, to design, within the ambit of the claims, a satisfactory zoom lens assembly other than the six specifically disclosed. Second, appellants' disclosure was said not to support their claims because their six examples are not representative of the ranges recited in the claims and, when challenged, appellants

[*1052] did not give a satisfactory explanation of [***6] the origin of the range limitations in the claims. We will discuss these two rationales in turn.

Opinion

A. Difficulty of designing an operative embodiment

It seems to have been agreed by all concerned that the design of commercially satisfactory zoom lenses of the kind involved here (i.e., four-member zoom lenses) is an extremely complex and time-consuming operation, even with the aid of modern computer techniques. Thus, quite apart from appellants' teachings, it would take a lens designer setting out to design a new zoom lens of this type many months, or even years, to come up with a marketable lens assembly possessing all the desired characteristics.

Appellants do not purport to have solved all of the time-consuming problems involved in the design of a new lens; indeed, to the extent that their relationships add new calculations to the design of zoom lenses, they may even have increased the time required. What they do claim to have done is to have discovered a simple set of relationships among some of the fundamental parameters involved in the design of zoom lenses which, if respected, will result in zoom lens assemblies which will be capable of zooming through a wider [***7] range than previous zoom lenses without experiencing an unacceptably high degree of image distortion at any point in their ranges of equivalent focal length variation. They are thus, it seems to us, somewhat in the position of a suspension-bridge builder who has discovered that maintaining certain relationships between the height above the roadway of the main piers and the distance between the peirs will result in bridges of substantially increased strength. Disclosure [**733] by the bridge builder of this relationship would certainly not solve all the time-consuming problems of bridge designing or building, but it would, we think, enable any person skilled in the art to practice the invention. Similarly, we feel that, while appellants' disclosure has not taught those skilled in the art how to design an entire new zoom lens in short order, it has taught those skilled in the art how to design a new zoom lens of the type here claimed without undue effort. The rejection therefore cannot be sustained on this rationale.

B. Support for the range limitations in the claims

The second problem, however, is more difficult. Appellants disclose six specific examples of lens assemblies [***8] embodying their invention, but they have claimed their invention in terms of broad ranges within which various parameters shall fall, which include but also go far beyond the specific examples. The examiner challenged the breadth of

[*1053] appellants' ranges, asking, "How could there be any lens design significance for all the values that can be chosen within the various broad ranges?" and demanding "Additional explanation * * * to explain the breadth of the ranges." As far as we can determine from the abbreviated record in this case, appellants never provided such "Additional explanation," ² contenting themselves with unsupported assertions, as quoted in the final action, that the range limitations

> 2 The closest they seem to have come to explaining the origin of the ranges in their application is the statement, contained in their Request for Reconsideration of the board's decision, that
>
> "[Appellants?] has [have?] in his [their?] possession a stack of paper three feet thick covered with calculations which resulted in the definition of the ranges set forth in the specification."

,"* * * cooperate with one another to form a complete combination, such that sufficiently [***9] good results are achieved, for all values within the specified ranges of variation for individual parameters, to produce the desired improvement over known objectives, provided of course that the designer makes appropriate use where necessary of the store of common general knowledge which all experts have."

On that record, the board affirmed the examiner's rejection "for substantially the reasons stated by the Examiner," but made an additional point by noting that

We consider the reasons which prompt the denial of broad claims to a chemical compound or a chemical process that is based on a single disclosed example are more than applicable here since few chemical processes or compounds involve as many parameters or as a high degree [as high a degree?] of precision as are evidenced in the case of the design of a complex lens and the predictability of securing the wanted results are much less than would be present in most chemical reactions.

Appellants rely on this court's decision in *In re Vickers, 31 CCPA 985, 141 F.2d 522, 61 USPQ 122 (1944)*, reversing the rejection of claims in a mechanical case reading on oil well pumping apparatus in which two valves were actuated by a [***10] single piston although appellants' specification disclosed actuation of the two valves by different pistons. The examiner had stated that "it * * * [was] not immediately clear" to him how both valves could be actuated by a single piston and that "applicants * * * [had] not shown how to do it." The board affirmed, stating (as paraphrased in the opinion of this court) that "an entirely different and unobvious construction from that shown in appellants' drawings and specification would be necessary in order to control the valves by a single piston." This court stated that it was "unable to concur in the view of the solicitor that appellant's specification does not suggest that * * * [both valves] could be operated [**734] by a single piston." The court found that "it is plainly suggested in appellants' specification that the accumulator piston alone may operate the valves for the purposes set forth in the appealed claims" and apparently

[*1054] accepted the explanation offered by counsel for appellants in their brief of the "obvious" manner in which this result could be achieved.

However, the opinion in Vickers does not stop there. It continues, noting but not answering [***11] "the question raised by counsel for appellants as to whether the tribunals of the Patent Office have authority to reject a broad claim merely because it may cover one or more inoperative species," but concluding that, even if they had such authority, the burden was on the Patent Office "to show that such a claim covers an inoperative species, and not upon the applicant to show that it does not." Clearly, since it had already held the single-piston valve-actuating structure an obvious variation of the disclosed two-piston valve-actuating structure, the court was of the view that the Patent Office had not carried this burden. Accordingly, it held that appellants had supported their broad claims by their disclosure of a single form of the claimed apparatus.

Vickers is cited in the Manual of Patent Examining Procedure, § 706.03(Z), for the proposition that "In mechanical cases, broad claims may properly be supported by a single form of an apparatus or structure." This statement is then contrasted with the rule "In chemical cases" that "the disclosure of a single species usually does not provide an adequate basis to support generic claims * * * because in chemistry it is not obvious [***12] from the disclosure of one species, what other species will work." This dichotomy, which we would prefer to see denominated a dichotomy between predictable and unpredictable factors in any art rather than between "mechanical cases" and "chemical cases," has been at the heart of much of the argument here, appellants contending that they are entitled to their broad claims by virtue of a single operative example because this is a "mechanical case" while the solicitor contends that appellants are entitled only to claims reading on their disclosed embodiments and obviously operative variations thereof.

[1] Preliminarily, it should be said that we regard the "question raised by counsel" and left open by this court in the Vickers case, as to the authority of the Patent Office to reject broad claims merely because they read on one or more inoperative species, as having been answered generally in the affirmative by subsequent cases. In 1949 the Supreme Court held that [HN1] claims may be too broad "to the point of invalidity "by reason of reading on significant numbers of inoperative embodiments. *Graver Tank & Mfg. Co. v. Linde Air Products Co., 336 U.S. 271, 276-77, 80 USPQ 451, 453 (1949)* [***13] (claims reading on all

[*1055] "silicates" or all "metallic silicates" when only nine metallic silicates "had been proved operative"). [3] [HN2] We see no reason why the Patent Office as well as the courts deciding infringement litigation should not "have authority to reject a broad claim merely because it * * * [reads on a significant number of] inoperative species." [4]

3 See also Goodman, "The Invalidation of Generic Claims by Inclusion of a Small Number of Inoperative Species," 40 JPOS 745 (1958), and Einhorn, "The Enforceability of Patent Claims Encompassing Some Inoperative Species," 45 JPOS 716 (1963). It should be noted that both Goodman and Einhorn focus on claims litigated in infringement actions, where equitable considerations may be present which are not present during the prosecution of patent applications, since an applicant is still in a position to amend his claims to exclude inoperative subject matter. Cf. *In re Prater, 56 CCPA 1381, 1396, 415 F.2d 1393, 1404-5, 162 USPQ 541, 550-1 (1969)*, and *In re Harwood, 55 CCPA 922, 926-7, 390 F.2d 985, 989, 156 USPQ 673, 676 (1968)*.

4 [2] [HN3] While we have held that "the mere possibility of inclusion of inoperative * * * [subject matter] does not prevent allowance of broad claims," *In re Sarett, 51 CCPA 1180, 1199, 327 F.2d 1005, 1019, 140 USPQ 474, 486 (1964)*, when the examiner sets forth reasonable grounds in support of his conclusion that an applicant's claims may read on inoperative subject matter (other than subject matter inoperative only in the sense of In re Skrivan, discussed infra), it becomes incumbent upon the applicant either to reasonably limit his claims to the approximate area where operativeness has not been challenged or to rebut the examiner's challenge either by the submission of representative evidence, *In re Harwood, supra, at 926, 390 F.2d at 989, 156 USPQ at 676*, or by persuasive arguments based on known laws of physics and chemistry, *In re Chilowsky, 43 CCPA 775, 782, 229 F.2d 457, 462, 108 USPQ 321, 325 (1956)*, and *In re Vickers, supra*.

[***14] [**735] However, [HN4] many patented claims read on vast numbers of inoperative embodiments in the trivial sense that they can and do omit "factors which must be presumed to be within the level of ordinary skill in the art," *In re Skrivan, 57 CCPA 1201, 427 F.2d 801, 806, 166 USPQ 85, 88 (1970)*, and therefore read on embodiments in which such factors may be included in such a manner as to make the embodiments inoperative. There is nothing wrong with this so long as it would be obvious to one of ordinary skill in the relevant art how to include those factors in such manner as to make the embodiment operative rather than inoperative. Ibid. See also Goodman, op. cit. note 3 at 748, and Einhorn, op. cit. note 3 at 719.

In this case appellants do not contend that every four-member lens assembly in which the specified parameters and parametric relation ships are kept within the recited ranges will be "useful" as a zoom lens in the sense of *35 USC 101*, nor that the specification teaches "how to use" those lens assemblies within the claims which are not "useful" as zoom lenses. [5] What appellants contend is that certain of such four-member lens assemblies will be useful as zoom lenses [***15] (indeed, that they will be superior in at least one sense to prior-art zoom lenses)

[*1056] and that it would be obvious to those skilled in lens design whether a given embodiment within the indicated ranges, once conceived, would or would not be useful as a zoom lens. Compare *In re Fisher, 57 CCPA 1099, 427 F.2d 833, 166 USPQ 18 (1970).* [HN5] The word "obvious" as here used means that those skilled in the art would know how to determine utility without having to build and try out the conceived embodiment and could do so without the expenditure of unreasonable effort. Cf. *In re Vickers, supra* (operability of single-piston device "obvious" from theoretical considerations unsupported - but unrebutted - by actual construction). Of course, given the complexities of zoom lens design, the determination, while routine, could be very time-consuming.

5 See Janicke, Patent Disclosure - Some Problems and Current Developments, Part II, "Undue Breadth as a Disclosure Problem," 52 JPOS 757 (1970), concerning the relationship between lack of *§ 101* utility and failure of the specification to teach "how to use" as required by *§ 112*.

As far as appellants' arguments go, they are persuasive. [***16] We agree that appellants' claims are not too broad "to the point of invalidity" just because they read on even a very large number of inoperative embodiments, since it seems to be conceded that a person skilled in the relevant art could determine which conceived but not-yet-fabricated embodiments would be inoperative with expenditure of no more effort than is normally required of a lens designer checking out a proposed set of parameters. In that sense, our reasoning here is similar to that which led us to reject the board's first rationale for its rejection under the first paragraph of *§ 112*.

However, appellants' arguments do not reach the heart of the board's second rationale, which, as we understand it, is that appellants, having been challenged to do so by the examiner, failed to demonstrate that the ranges of parameters and parametric relationships recited in the claims reasonably bound the area within which satisfactory zoom lenses could be produced by ordinary design skill. The examiner in effect, and reasonably in our estimation, challenged appellants to prove that there were embodiments to be found, not only near the six [**736] specifically disclosed examples, but [***17] at various points throughout the broader claimed ranges, which would be operative. Appellants asserted that they had made "calculations which resulted in the definition of the ranges set forth in the specification," but they never produced those calculations to substantiate the truthfulness of the teaching in their specification which the examiner challenged. *[3] Section 112* [HN6] requires not that the specifications merely say how to use the claimed invention, but that such teaching be true, i.e., in fact enabling. Appellants having failed to establish the truthfulness of their assertions about the validity of their ranges when reasonably challenged to do so by the examiner, we hold that the Patent Office properly rejected the appealed claims. The decision of the board is affirmed.

ATTACHMENT BQ

350-427 SR

OR 3,736,048

United States Patent [19]

Cook et al.

[11] 3,736,048

[45] May 29, 1973

SUBSTITUTE FOR MISSING OR

[54] **OPTICAL OBJECTIVES OF VARIABLE EQUIVALENT FOCAL LENGTH**

[75] Inventors: **Gordon Henry Cook**, Oadby, England; **Peter Arnold Merigold**, Prestatyn, Wales

[73] Assignee: **The Rank Organization Limited**, London, England

[22] Filed: June 11, 1971

[21] Appl. No.: 152,284

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 309,206, Sept. 16, 1963, abandoned.

[52] **U.S. Cl.** 350/186, 350/187, 350/214

[51] **Int. Cl.** G02b 7/10, G02b 15/18

[58] **Field of Search** 350/184, 186

[56] **References Cited**

UNITED STATES PATENTS

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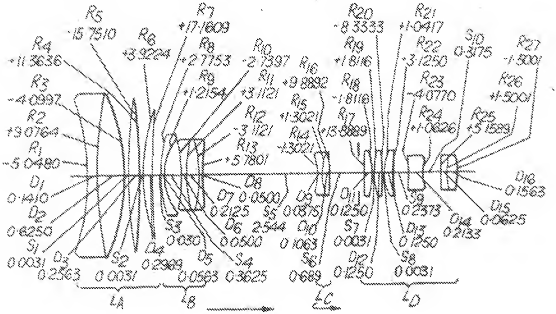
Primary Examiner—John K. Corbin
Attorney—Holcombe, Wetherill & Brisebois

[57] **ABSTRACT**

A zoom lens having an improved zooming range and comprising a convergent first member which for a given object distance remains stationary during the zooming relative movements, an axially movable divergent second member behind the first member having equivalent focal length f_B lying numerically between 4 and 8 times the minimum value of the ratio of the equivalent focal length of the complete objective to the f-number of the objective in the range of variation, an axially movable divergent third member behind the second member having equivalent focal length f_C lying numerically between 5 and 10 times the minimum value of such ratio, a stationary convergent fourth member behind the third member, a zoom control element, and means whereby operation of the zoom control element causes the zooming relative movements to be effected, wherein the total axial movement of the second member in the range of variation lies numerically between $1.5f_B$ and $2.5f_B$ and the total axial movement of the third member in the range lies numerically between $0.25f_C$ and $0.5f_C$, the minimum axial separation between the second and third members occurring when the equivalent focal length of the object is greater than half its maximum value in the range of variation, the movable divergent second member consisting of a divergent simple meniscus component with its surfaces convex to the front and a divergent compound component behind such simple component, and the movable divergent third member consisting of a doublet component having its front surface concave to the front with radius of curvature lying numerically between $0.5f_C$ and $1.0f_C$.

22 Claims, 7 Drawing Figures



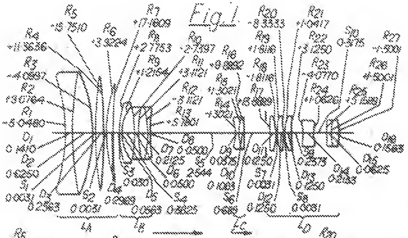


Fig. 1

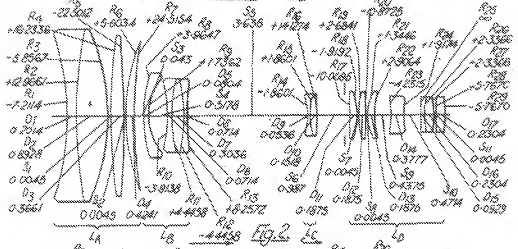


Fig. 2

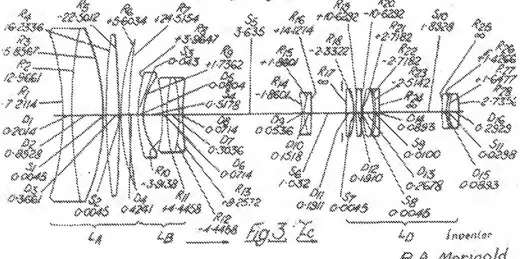


Fig. 3

Inventor

P. A. Merigold

By G. H. Cook

Attorneys

Fig. 4.

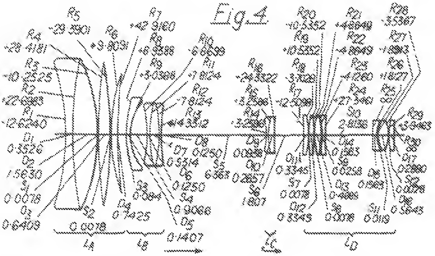


Fig. 5.

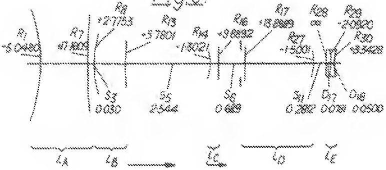
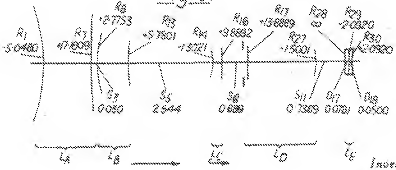


Fig. 6.



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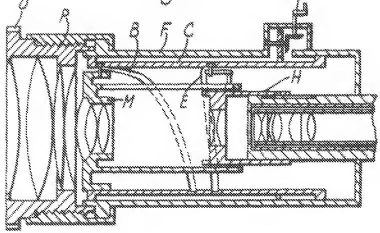
By

Attorneys

Fig. 7.



OPTICAL OBJECTIVES OF VARIABLE EQUIVALENT FOCAL LENGTH

This application is a continuation-in-part of our prior application Ser. No. 309,208, filed Sept. 16, 1963, now abandoned.

This invention relates to an optical objective of the "zoom" type, that is of the type having relatively movable members whereby under the control of a zoom control element the equivalent focal length of the objective can be continuously varied throughout a range, whilst maintaining constant position of the image plane, whereby the scale of the image can be varied, the objective being corrected for spherical and chromatic aberration, coma, astigmatism, field curvature and distortion. In this type of objective, accommodation for change of object position is usually achieved by imparting a movement, independent of the zooming relative movements, to the front member of the objective.

Many difficulties arise in the design of such objectives, and one of the problems facing designers of today is to achieve an increased range of variation of equivalent focal length and, where possible, also an increased angular field of view. Attempts to achieve this have usually involved the use of relatively complicated movable members in the objective in order to make it possible to stabilize the aberrations throughout the range of variation, such stabilised aberrations then being compensated in a stationary rear member of the objective which also serves to locate the resultant image plane in a convenient position. This in turn involves the use of relatively large and heavy movable members and not only increases the bulk and size of the complete objective, but also presents severe mechanical problems in controlling the movements, especially bearing in mind that at least one of the movable members must necessarily perform a movement bearing a non-linear relationship to the movement of the zoom control element. Many attempts to extend the range of variation of the equivalent focal length have failed, because they have demanded departures from linearity of movement which are impracticable mechanically, and often too because they have involved an increase in the bulk and size of the objective to unmanageable proportions or have introduced too severe optical difficulties in achieving aberration correction.

One way of reducing the mechanical complexities is so to arrange the system that the front member does not participate in the zooming movements for varying the equivalent focal length, so that this member is concerned only with focussing movements and is relieved of the complication of superimposing focussing movements on zooming movements. Such an arrangement is utilised in the present invention, wherein the primary object is to provide an improved arrangement of the movable zooming system of the objective, which can be employed with various different arrangements of the front member and will cooperate therewith to enable aberration stability to be achieved throughout a widely extended range of variation of the equivalent focal length of the objective.

BRIEF SUMMARY OF THE INVENTION

The optical objective of the zoom type according to the present invention has four members of which the first (counting from the front) for a given object distance remains stationary during the zooming relative movements, the second and third are divergent and movable, and the fourth is convergent and stationary, the minimum separation between the second and third members occurring when the equivalent focal length of the objective is greater than half its maximum value in the range of variation, whilst the equivalent focal lengths f_B and f_C respectively of the movable second and third members lie numerically respectively between 4 and 8 times the minimum value of the ratio of the equivalent focal length of the objective to the f-number of the objective in the range of variation and between 5 and 10 times such minimum ratio, the divergent movable second member consisting of a divergent simple meniscus component with its surfaces convex to the front followed by a divergent compound component and performing during the range of variation a total axial movement lying numerically between $1.5 f_B$ and $2.5 f_B$, whilst the divergent movable third member consists of a doublet component having a front surface concave to the front with radius of curvature lying numerically between $0.5 f_C$ and $1.0 f_C$ and performs during the range of variation a total axial movement lying numerically between $0.25 f_C$ and $0.5 f_C$.

Several specific examples of optical objectives as above described will be given later on in this specification, and a table will be found after the first example, together with an accompanying explanation showing the effect of varying those parameters for which ranges of variation are given in the preceding paragraph within the ranges specified in that paragraph.

It is to be understood that the terms "front" and "rear", as used herein, relate respectively to the sides of the objective nearer to and further from the longer conjugate in accordance with the usual convention.

In addition, the term "total axial movement" is used to refer to the total distance moved by a member during zooming from one end of the range to the other, independently of the direction of movement. Thus, a member may move forward and then back during the range of variation, and in this case the total axial movement is the numerical sum of the forward distance moved plus the rearward distance moved.

It should also be made clear that the term "internal contact", when used in connection with a compound component, is intended to include, not only a cemented contact, but also what is commonly known as a "broken contact", that is one in which the two contacting surfaces have slightly different radii of curvature, the effective radius of curvature of such a broken contact being the arithmetic mean between the radii of curvature of the individual contacting surfaces, whilst the optical power of the broken contact is the harmonic mean between the optical powers of the individual contacting surfaces.

The characteristics of the movable second and third members above specified contribute towards keeping the overall dimensions of the objective as small as possible and achieving the best compromise between the diameters and the relative apertures of the individual members of the objective, and also permit the front nodal points of the second and third members to be located as far forward as possible, thus making it possible, not only to accommodate the desired movements of the members without risk of fouling between the members and with minimum increase in the overall length of the objective, but also to achieve a good compromise between the diameters and relative apertures

of the individual members, and at the same time to assist towards the desired stabilization of the aberrations, especially of spherical aberration and coma, throughout a widely extended range of variation of the equivalent focal length of the objective.

FURTHER FEATURES OF THE INVENTION

The compound component in the divergent movable second member preferably includes at least one convergent element and at least one divergent element made of materials whose Abbe V numbers differ from one another by more than 25, thus permitting such second member to be individually corrected for chromatic aberration.

For assisting towards stabilization of astigmatism and distortion, the radius of curvature of the front surface of the simple meniscus component of the second member preferably lies numerically between $1.5f_B$ and $3f_B$, and further assistance towards stabilization of astigmatism can be obtained by arranging for the radius of curvature of the rear surface of such component to lie numerically between $0.66f_B$ and $1.0f_B$.

The front surface of the compound component of the second member is preferably concave to the front with radius of curvature lying numerically between $1.5f_B$ and $3f_B$, the rear surface of such component being convex to the front with radius of curvature lying numerically between $3f_B$ and $6f_B$, thus assisting towards stabilization of spherical aberration and coma.

Whilst such compound component may consist of a doublet component, it will usually be preferable for it to be in the form of a triplet component having a convergent element between two divergent elements. This, in view of the limited availability of suitable materials for the various elements, facilitates correction of chromatic aberration and the desired stabilization of the other aberrations without excessive curvature of the individual surfaces.

The avoidance of excessive surface curvatures can also be assisted by employing for all the elements of the second member materials whose mean refractive indices are greater than 1.65, whilst the mean refractive indices of the materials of the elements of the compound component in such member do not differ from one another by more than 0.15. The arithmetic mean between the Abbe V numbers of the materials of the divergent elements in the second member preferably exceeds that of the convergent element or elements by at least 25, in order to assist in correcting such member for chromatic aberration.

The doublet component constituting the divergent movable third member preferably has a collective internal contact convex to the front with radius of curvature lying numerically between $0.5f_C$ and f_C, the difference between the mean refractive indices of the materials of the two elements of such component lying between 0.05 and 0.15, whilst the difference between the Abbe V numbers of such materials exceeds 25. These features contribute towards the desired stabilization of the spherical aberration and coma and also facilitate individual correction of the third member for chromatic aberration.

As in the case of the second member, it is preferable to employ materials for the elements of the third member having mean refractive indices greater than 1.65, in order to avoid excessive surface curvatures and thus

facilitate the attainment of a wide relative aperture for the member.

A movable system arranged in the manner above described in accordance with the present invention is suitable for use with various different arrangements of the first member of the objective, but it is especially advantageous for such member to have one or more of the following characteristics:

A. The first member is preferably convergent and may comprise a front meniscus doublet component with its front and rear surfaces concave to the front followed by two simple convergent components, the front surface of the doublet component having dispersive optical power lying numerically between $0.5/f_A$ and $1.0/f_A$, where f_A is the equivalent focal length of the first member. These features permit the rear nodal point of the first member to be far to the rear and preferably behind the rear surface of the member, for cooperation with the forwardly located front nodal point of the second member.

B. The internal contact of the meniscus doublet component of the first member may be dispersive and convex to the front with radius of curvature between $1.5f_A$ and $3f_A$, the difference between the mean refractive indices of the materials of the two elements of such doublet component being greater than 0.15. These features contribute towards stabilization of spherical aberration and astigmatism over the desired focussing range to suit different object distances.

C. The two simple components of the first member may together have a combined equivalent focal length between $0.75f_A$ and $1.25f_A$, their front surfaces each being convex to the front, the radius of curvature of the front surface of the first of such simple components being less than $4f_A$ and greater than twice the radius of curvature of the front surface of the second of such simple components, which latter radius of curvature may in turn be greater than $0.75f_A$. These features assist towards stabilizing the aberrations, especially spherical aberration and astigmatism, not only throughout the range of focussing adjustments, but also throughout the range of variation of equivalent focal length.

D. The rear surface of the rear component of the first member may be convex to the front with radius of curvature between $2f_A$ and $7f_A$. This feature contributes towards stabilization of primary astigmatism throughout the range of focussing adjustments, and also of primary and higher order astigmatism throughout the range of variation of equivalent focal length.

E. The axial thickness of the meniscus doublet component of the first member may be less than $0.25f_A$ and greater than the sum of the axial thicknesses of the two simple components thereof, such sum in turn being greater than $0.075f_A$. These features contribute towards the desired rearward location of the rear nodal point of the first member.

F. The arithmetic mean between the Abbe V numbers of the material of the three convergent elements of the first member may exceed by at least 20 the Abbe V number of the material of the divergent front element of the meniscus doublet component of such member, thus facilitating individual correction of the first member for chromatic aberration.

G. The equivalent focal length f_A of the first member may lie between 1.2 and 2.4 times the maximum value of the ratio of the equivalent focal length of the objective to the f-number of the objective. This feature as-

sists towards keeping the overall dimensions of the objective and also the relative aperture of the first member as small as possible.

H. If desired, an achromatic doublet component may be provided, which can be placed at will behind the rear member of the objective to increase the value of the equivalent focal length of the objective by a chosen ratio throughout the range of variation.

In all the arrangements according to the present invention, it is preferable for the iris diaphragm of the objective to be stationary and to be located behind the movable third member of the objective.

DESCRIPTION OF EMBODIMENTS

Some convenient practical examples of zoom objective according to the invention are illustrated diagrammatically in the accompanying drawings, in which

FIGS. 1 – 4 respectively illustrate four examples (FIG. 4 being on half the scale of FIGS. 1 – 3),

FIGS. 5 – 6 show the example of FIG. 1 (in skeleton form) modified by the addition respectively of two alternative constructions of achromatic doublet component detachably mounted behind the rear member of the objective, and

FIG. 7 is an axial section through a lens mount having suitable zoom control element for use in carrying out the invention.

Numerical data for those six examples are given in the following tables (numbered correspondingly to the figures of the drawings), in which R_1, R_2 . . . designate the radii of curvature of the individual surfaces of the objective counting from the front, the positive sign indicating that the surface is convex to the front and the negative sign that it is concave thereto, D_1, D_2 . . . designate the axial thicknesses of the individual elements of the objective, and S_1, S_2 . . . designate the axial air separations between the components of the objective. The tables also give the mean refractive indices n_d for the d-line of the spectrum and the Abbe V numbers of the materials from which the various elements of the objective are made, and in addition the clear diameters of the various surfaces of the objective.

The second section of each table gives the values of the three variable axial air separations between the four members of the objective for a number of representative positions, for which the corresponding values of the equivalent focal length F of the complete objective from its minimum value F_a to its maximum value F_m are also given, together with the corresponding values of log F.

Some of the tables also have a third section giving the equation defining an axial section through an aspheric surface provided in the stationary rear member of the objective, the radius of curvature given for such surface in the first section of the table being the radius of curvature at the vertex of the surface.

The dimensions in each table are given in terms of F_a.

The insertion of equals (=) signs in the radius columns of the tables, in company with plus (+) and minus (−) signs which indicate whether the surface is convex or concave to the front, is for conformity with the usual Patent Office custom, and it is to be understood that these signs are not to be interpreted wholly in their mathematical significance. This sign convention agrees with the mathematical sign convention required for the computation of some of the aberrations including the primary aberrations, but different mathematical sign conventions are required for other purposes including computation of some of the secondary aberrations, so that a radius indicated for example as positive in the tables may have to be treated as negative for some calculations as is well understood in the art.

EXAMPLE 1

Radius	Thickness or air separation	Refractive index n_d	Abbe V number	Clear diameter
R_1 = −3.0869				R_1 3.4[illegible]
	D_1 = 0.3519	1.7[illegible]	[illegible]	
R_2 = +41.0794				R_2 3.4750
	D_2 = 0.0996	1.5[illegible]	[illegible]	
R_3 = −4.2697				R_3 3.[illegible]
	S_1 = 0.4501			
R_4 = +11.3838				R_4 3.3715
	D_3 = 0.2603	1.517	42.[illegible]	
R_5 = −16.2610				R_5 3.3635
	S_2 = 0.0031			
R_6 = +18.8734				R_6 3.[illegible]
	D_4 = 0.3665	1.517	42.[illegible]	
R_7 = +17.1609				R_7 3.0[illegible]
	S_3 = Variable			
R_8 = +2.7760				R_8 1.7[illegible]
	D_5 = 0.0865	1.[illegible]	[illegible]	
R_9 = +1.2354				R_9 1.[illegible]
	S_4 = 0.3825			
R_{10} = −2.2297				R_{10} 1.4[illegible]
	D_6 = 0.0506	1.[illegible]	[illegible]	
R_{11} = +3.[illegible]				R_{11} 1.4[illegible]
	D_7 = 0.2528	1.78[illegible]	[illegible]	
R_{12} = −3.1173				R_{12} 1.3[illegible]
	D_8 = 0.0506	1.[illegible]	[illegible]	
R_{13} = +15.7601				R_{13} 1.3[illegible]
	S_5 = Variable			
R_{14} = −1.3071				R_{14} 0.[illegible]
	D_9 = 0.0375	1.[illegible]	[illegible]	
R_{15} = +1.3021				R_{15} 0.8[illegible]
	D_{10} = 0.1588	1.78[illegible]	[illegible]	
R_{16} = +10.8[illegible]				R_{16} 0.8[illegible]
	S_6 = Variable			
R_{17} = +12.8660				R_{17} 0.8[illegible]
	D_{11} = 0.1250	1.[illegible]	[illegible]	
R_{18} = −1.0118				R_{18} 0.8[illegible]
	S_7 = 0.0083			
R_{19} = +3.[illegible]				R_{19} 0.[illegible]
	D_{12} = 0.1250	1.[illegible]	[illegible]	
R_{20} = −8.3232				R_{20} 0.[illegible]
	S_8 = 0.0083			
R_{21} = +7.[illegible]				R_{21} 0.[illegible]
	D_{13} = 0.1250	1.[illegible]	[illegible]	
R_{22} = +3.1250				R_{22} 0.[illegible]
	S_9 = 0.2333*			
R_{23} = −4.0[illegible]				R_{23} 0.[illegible]
	D_{14} = 0.7333	1.7[illegible]	[illegible]	
R_{24} = +1.0625				R_{24} 0.[illegible]
	S_{10} = 0.3175			
R_{25} = +6.3563				R_{25} 0.7[illegible]
	D_{15} = 0.0625	1.7[illegible]	[illegible]	
R_{26} = +1.2088				R_{26} 0.[illegible]
	D_{16} = 0.1563	1.[illegible]	[illegible]	
R_{27} = −1.2088				R_{27} 0.[illegible]

* Aspheric

S_3	S_5	S_6	F	log F
0.03023	2.34423	0.58858	1.00000	0.00
1.11809	1.40738	0.74157	1.77827	0.25
1.93430	0.60733	0.72521	3.16227	0.50
2.55076	0.16104	0.55123	5.62339	0.75
2.98233	0.14657	0.13434	10.00000	1.00

Equation for aspheric surface R_{22}

$$x = -4.077 + \sqrt{16.[illegible] - y^2} - 0.02459303\, y^4 + 0.08899172\, y^6 - 0.2440590\, y^8 - 0.07442450\, y^{10}$$

The foregoing Example describes a complete thick lens design, with values calculated in many cases to the fourth decimal place, and several additional Examples of this type will be given subsequently.

It is, however, obviously impractical to provide such fully calculated thick lens designs for values broadly distributed throughout the previously specified ranges for all the significant parameters.

However, in order to show the effect of altering the principal parameters within the ranges specified for those parameters, and demonstrate the practicality of designing lenses having parameter values near the ex-

tremes of the specified ranges, an illustrative table is given below. The parameters given are all thin lens parameters (parameters of the thin lens construction on which Example I is based) and the effects of these parameter variations are shown on the dimensions of the overall objective and the relative apertures (f-numbers) of the first three members.

In the following table:

F_B is the focal length of the second member;
F_C is the focal length of the third member;
T_B is the total axial movement of the second member;
T_C is the total axial movement of the third member;
R is the minimum value of the ratio of the focal length of the complete objective to its f-number;
L is the overall length from the front of the objective to the focal plane;
D is the maximum diameter at the front of the objective;
F_{N1} is the relative aperture of the first member;
F_{N2} is the relative aperture of the second member; and
F_{N3} is the relative aperture of the third member.

The four critical thin lens parameters set forth in the fifth paragraph of this specification and in the main claim are F_B, F_C, T_B, and T_C, and their values for Example I are shown in line 1 of the table. In line 2, F_B is put equal to the lower limit (4R) of the main claim, and in line 3 equal to the upper limit (8R). In lines 4 and 5 F_C is treated similarly. T_B and T_C are dealt with in similar manner in lines 6 and 7 and lines 8 and 9. It is not possible to vary the four parameters completely independently of one another (this is referred to again later), and in fact when one parameter is set to an end limit, at least two of the others have been adjusted, in the table, so that the range of variation of focal length remains approximately unchanged.

Line 3 shows the effect of putting F_B to its upper limit. Conversely, from the changes in L, D, F_{N1}, F_{N2} and F_{N3} it can be seen that such a modified thin lens construction would be suitable for development of a final objective of relatively simple construction constructed to cover relatively large image format dimensions (at which scale high complexity would not be permissible) at a smaller relative aperture than Example I.

Lines 4 and 5 show identical effects achievable by putting F_C at its lower and upper limits.

Line 6 shows the effect of putting the total axial movement of the second member at its upper limit. In fact, in order to do this, it is necessary to put at least either F_B or F_C at or near its end limit. This is dictated by the fundamental laws of optics, also bearing in mind the requirement to keep the focal range roughly the same. However, the effect is now not quite the same as in lines 2 to 5, because one axial movement now also lies at its end limit. Thus, the change in L and D from Example I is reduced, while the relative aperture of one member (the third member) is increased but the other two are reduced. Lines 7 to 9 show similar effects; in extent from Example I, as also are F_{N1}, F_{N2} and F_{N3}. Reverting to line 6 in particular, this modification is suited to a moderately small but not extremely small dimensional scale of final objective having a medium relative aperture, wherein the smaller relative aperture of the third member either permits its complexity to be reduced or, more usefully, its existing complexity utilized to achieve an extremely high standard of aberration correction. Corresponding but slightly different effects can be seen from the modifications of lines 7 to 9.

In general therefore, it can readily be seen from the table how the parameters of the main claim can be taken to their end limits to provide differing effects suited to differing initial requirements. The lens de-

	F_B	F_C	T_B	T_C	L	D	F_{N1}	F_{N2}	F_{N3}
Example I	−1.47	−1.81	1.78	0.66	3.07	2.81	1.60	1.0	2.28
F_B=1.0(4R)	−1.0	−1.82	1.73	0.35	2.90	2.56	1.34	0.80	2.19
F_B=2.0(8R)	−2.0	−1.81	2.60	0.77	4.38	3.17	1.75	1.08	2.83
[illegible]	−1.47	−1.70	2.48	0.58	3.11	2.67	1.60	1.00	1.87
[illegible]	−1.47	−2.30	1.38	0.77	3.01	2.85	1.33	0.98	3.07
[illegible]	−1.6	−2.28	1.56	0.90	3.34	2.80	1.48	0.91	2.78
[illegible]	−2.0	−1.78	3.10	0.64	2.88	2.67	1.38	1.08	1.70
[illegible]	−1.6	−2.00	2.57	0.98	3.06	2.60	1.48	0.91	2.78
[illegible]	−2.0	−1.88	2.33	0.72	2.31	2.60	1.62	1.08	1.75

Example I is a zoom lens intended for construction to a medium dimensional scale to cover average format dimensions.

In line 2, the effect of putting F_B to its lower limit is to reduce L and D. F_{N1}, F_{N2} and F_{N3} are also reduced, meaning that each individual member has a wider relative aperture. Because of their wider relative apertures, these members would have to be more complex (contain more usable thick lens parameters) than they are in Example I, in order to achieve the same high standard of aberration correction. However, this greater complexity would be acceptable for a zoom objective built to a small dimensional scale covering small image format dimensions. Such a small scale construction would readily be possible in view of the reductions in L and D. Therefore, a zoom lens within the scope of the main claim, with F_B at or near its lower limit, would be preferred for a lens of wider relative aperture but constructed to a smaller dimensional scale than Example I.

signer given the main claim and having a particular end requirement can work accordingly.

The table also demonstrates the sense of the end limits. For example, to take F_B below the value of 1.0(4R) in line 2 would be further to decrease L and D and further widen the relative apertures of the second, third and fourth members. Obviously a question of opinion is involved at this point, but the opinion of the inventor is that the complexity of construction for the second to fourth members, in order to achieve good aberration correction at the further widened relative aperture, would render a practical construction a non-commercial proposition. Likewise to take F_B beyond the value of 2.0(8R) in line 3 would only permit construction of a practical corrected objective to such a large dimensional scale that it would find no useful application. The same factors also arise in the modifications of lines 6 to 9, when coupled with the requirement to maintain a large range of variation of focal length, which is an essential object of the invention.

EXAMPLE II

Radius	Thickness or air separation	Refractive index n_d	Abbe V number	Clear diameter
$R_1=-7.2314$				R_1 3.9190
	$D_1=0.2834$	1.7847	26.10	
$R_2=+12.9801$				R_2 3.9642
	$D_2=0.8208$	1.5150	55.26	
$R_3=-5.9867$				R_3 4.9814
	$S_1=0.0046$			
$R_4=+36.2236$				R_4 4.8104
	$D_3=0.3601$	1.7170	47.90	
$R_5=-73.8012$				R_5 4.8014
	$S_2=0.0046$			
$R_6=-15.6064$				R_6 4.6386
	$D_4=0.4481$	1.7170	47.90	
$R_7=+26.3158$				R_7 4.3667
	S_3=Variable			
$R_8=+3.5687$				R_8 2.4086
	$D_5=0.0804$	1.69734	56.10	
$R_9=+3.7869$				R_9 2.4181
	$S_4=0.3178$			
$R_{10}=-3.9188$				R_{10} 2.1018
	$D_6=0.0614$	1.69736	56.10	
$R_{11}=+4.4486$				R_{11} 2.0182
	$D_7=0.3038$	1.7847	26.10	
$R_{12}=-8.3458$				R_{12} 1.8925
	$D_8=0.0714$	1.69736	56.19	
$R_{13}=+8.3374$				R_{13} 1.8188
	S_5=Variable			
$R_{14}=-1.8605$				R_{14} 1.1458
	$D_9=0.0806$	1.69736	56.19	
$R_{15}=+1.8605$				R_{15} 1.1731
	$D_{10}=0.3019$	1.7847	26.10	
$R_{16}=+16.1374$				R_{16} 1.1957
	S_6=Variable			
$R_{17}=-10.0085$				R_{17} 1.2080
	$D_{11}=0.1825$	1.5168	64.20	
$R_{18}=-1.7370$				R_{18} 1.2884
	$S_7=0.0046$			
$R_{19}=+2.8845$				R_{19} 1.3610
	$D_{12}=0.1855$	1.5168	64.20	
$R_{20}=-10.8725$				R_{20} 1.3098
	$S_8=0.0046$			
$R_{21}=+1.2416$				R_{21} 1.2873
	$D_{13}=0.1875$	1.5168	64.20	
$R_{22}=+2.0961$				R_{22} 1.2269
	$D_{14}=0.4815$			
$R_{23}=-4.2315$				R_{23} 1.0600
	$D_{15}=0.2727$	1.7283	28.68	
$R_{24}=+1.2176$				R_{24} 0.9888
	$S_9=0.8734$			
$R_{25}=\infty$				R_{25} 1.0036
	$D_{16}=0.0979$	1.7283	28.68	
$R_{26}=+3.2160$				R_{26} 1.0088
	$D_{17}=0.2004$	1.6384	60.27	
$R_{27}=-1.2095$				R_{27} 1.0188
	$S_{10}=0.0044$			
$R_{28}=+3.7876$				R_{28} 1.0086
	$D_{18}=0.2804$	1.6384	60.27	
$R_{29}=-3.2576$*				R_{29} 0.9718

*Aspheric.

S_3	S_5	S_6	F	log F
0.04318	3.63462	0.98730	1.00000	0.00
1.39158	2.01054	1.06388	1.77827	0.25
2.76329	0.86219	1.03962	3.16227	0.50
3.64395	0.23005	0.79109	5.62339	0.75
4.23190	0.23796	0.19524	10.00000	1.00

Equation for aspheric surface R_{29}

$$x = -4.2315 + \sqrt{17.90559 - y^2} - 0.01666805\, y^4 + 0.07010843\, y^6 - 0.00176346\, y^8 - 0.00533820\, y^{10}$$

EXAMPLE III

Radius	Thickness or air separation	Refractive index n_d	Abbe V number	Clear diameter
$R_1=-7.1734$				R_1 4.0702
	$D_1=0.2834$	1.7847	26.10	
$R_2=+12.9801$				R_2 4.9642
	$D_2=0.8208$	1.5168	55.26	
$R_3=-5.9867$				R_3 4.9814
	$S_1=0.0046$			
$R_4=+35.2236$				R_4 4.8104
	$D_3=0.3601$	1.7170	47.90	
$R_5=-73.8012$				R_5 4.8014
	$S_2=0.0046$			
$R_6=-15.6064$				R_6 4.6386
	$D_4=0.4481$	1.7170	47.90	
$R_7=+26.3158$				R_7 4.3667
	S_3=variable			
$R_8=+3.5687$				R_8 2.4086
	$D_5=0.0804$	1.69736	56.10	
$R_9=+4.7286$				R_9 2.4167
	$S_4=0.3178$			
$R_{10}=-3.9188$				R_{10} 2.1018
	$D_6=0.0614$	1.69736	56.10	
$R_{11}=+4.4486$				R_{11} 2.0182
	$D_7=0.3038$	1.7847	26.10	
$R_{12}=-8.3458$				R_{12} 1.9035
	$D_8=0.0714$	1.69736	56.10	
$R_{13}=+8.3374$				R_{13} 1.9181
	S_5=variable			
$R_{14}=-1.8605$				R_{14} 1.1163
	$D_9=0.0806$	1.69736	56.19	
$R_{15}=+1.8605$				R_{15} 1.1738
	$D_{10}=0.3019$	1.7847	26.10	
$R_{16}=+16.1374$				R_{16} 1.1963
	S_6=variable			
$R_{17}=\infty$				R_{17} 1.2850
	$D_{11}=0.1875$	1.518	58.82	
$R_{18}=-7.3859$				R_{18} 1.3098
	$S_7=0.0046$			
$R_{19}=+10.0282$				R_{19} 1.3078
	$D_{12}=0.1810$	1.518	58.82	
$R_{20}=-10.0282$				R_{20} 1.3098
	$S_8=0.0046$			
$R_{21}=+2.7812$				R_{21} 1.3279
	$D_{13}=0.2078$	1.65160	58.22	
$R_{22}=-2.7812$				R_{22} 1.3068
	$S_9=0.8100$			
$R_{23}=-2.8741$				R_{23} 1.2692
	$D_{14}=0.0888$	1.72000	28.05	
$R_{24}=\infty$				R_{24} 1.2683
	$S_{10}=1.8835$			
$R_{25}=\infty$				R_{25} 0.9898
	$D_{15}=0.0882$	1.72000	28.04	
$R_{26}=+1.4286$				R_{26} 0.9898
	$S_{11}=0.0088$			
$R_{27}=+1.8677$				R_{27} 0.9898
	$D_{16}=0.0838$	1.69736	56.19	
$R_{28}=-1.7320$				R_{28} 0.9898

S_3	S_5	S_6	F	log F
0.04318	3.63462	1.0319	1.00000	0.00
1.39158	2.01054	1.1076	1.77827	0.25
2.76329	0.86219	1.08423	3.16227	0.50
3.64395	0.23005	0.83569	5.62339	0.75
4.23190	0.23796	0.23984	10.00000	1.00

EXAMPLE IV

Radius	Thickness or air separation	Refractive index n_d	Abbe V number	Clear diameter
$R_1=-33.6040$				R_1 8.6115
	$D_1=0.3530$	1.7847	25.70	
$R_2=+22.6950$				R_2 8.6860
	$D_2=1.3650$	1.5168	55.36	
$R_3=-16.2026$				R_3 8.7203
	$S_1=0.0078$			
$R_4=+26.4198$				R_4 8.4815
	$D_3=0.8406$	1.7170	47.90	
$R_5=-29.3950$				R_5 8.4050
	$S_2=0.1078$			
$R_6=+7.8098$				R_6 7.2011
	$D_4=0.2425$	1.7170	47.90	
$R_7=+12.9190$				R_7 7.0290
	S_3=Variable			
$R_8=+3.9388$				R_8 4.3086
	$D_5=0.1487$	1.6968	55.52	
$R_9=+13.0888$				R_9 3.3062
	$S_4=0.7800$			
$R_{10}=-4.8890$				R_{10} 3.6775
	$D_6=0.1250$	1.6968	55.52	
$R_{11}=+3.8873$				R_{11} 3.5245
	$D_7=0.3814$	1.78470	26.10	
$R_{12}=-3.4838$				R_{12} 3.4636
	$D_8=0.1250$	1.6968	55.52	
$R_{13}=+14.3337$				R_{13} 3.2014
	S_5=Variable			
$R_{14}=-8.1686$				R_{14} 1.6231
	$D_9=0.1628$	1.6968	55.52	
$R_{15}=+8.1686$				R_{15} 1.6586
	$D_{10}=0.3627$	1.7847	26.10	
$R_{16}=+26.8803$				R_{16} 1.6814
	S_6=Variable			
$R_{17}=-12.8008$				R_{17} 2.2274
	$D_{11}=0.2885$	1.6968	55.60	
$R_{18}=-3.7908$				R_{18} 2.2196
	$S_7=0.0078$			
$R_{19}=+10.3889$				R_{19} 2.2812
	$D_{12}=0.2885$	1.6968	55.60	
$R_{20}=-10.3889$				R_{20} 2.2881
	$S_8=0.0078$			
$R_{21}=+4.8660$				R_{21} 2.2882
	$D_{13}=0.4662$	1.6385	55.27	
$R_{22}=-4.8660$				R_{22} 2.2250
	$S_9=0.0078$			
$R_{23}=-4.1280$				R_{23} 2.1348
	$D_{14}=0.1563$	1.7283	28.66	
$R_{24}=+27.3685$				R_{24} 2.1692
	$S_{10}=2.8138$			
$R_{25}=\infty$				R_{25} 2.2178
	$D_{15}=0.1563$	1.7283	28.68	
$R_{26}=+1.8737$				R_{26} 2.2048
	$S_{11}=0.0134$			
$R_{27}=+1.8412$				R_{27} 1.7282
	$D_{16}=0.3863$	1.6385	55.60	
$R_{28}=-2.5367$				R_{28} 1.6743
	$S_{12}=0.0078$ *			
$R_{29}=+3.3468$				R_{29} 1.3754
	$D_{17}=0.3800$	1.6568	55.60	
$R_{30}=\infty$				R_{30} 1.3796

* Aspheric.

S_1	S_A	S_B	F	log F
0.08424	6.36337	1.80703	1.00000	0.0
2.79613	3.51789	1.93436	1.77827	0.25
4.84658	1.20841	1.87864	3.16227	0.5
6.38837	0.47269	1.68352	5.62339	0.75
7.41774	0.41852	1.42502	10.00000	1.0

Equation for aspheric surface R_{20}

$$z = +3.9463 - \sqrt{15.37703 - y^2} + 0.00427020\ y^4 - 0.00777096\ y^6 + 0.00721693\ y^{10}$$

In all these examples, the maximum value F_M of the equivalent focal length F of the objective is ten times the minimum value F_o thereof. Example I is corrected for a relative aperture f/4.0, whilst Examples II and III are each corrected for a relative aperture f/2.8, and Example IV is corrected for a relative aperture of f/1.6. Examples II and III differ from one another solely in the stationary rear member L_D, the front three members L_A, L_B and L_C being identical in the two examples. Such members L_A, L_B and L_C are in fact similar to the front three members L_A, L_B and L_C of Example I, the dimensions being scaled up from those of Example I in the ratio of the f-numbers, that is in the ratio of 4.0/2.8. The rear members L_D in Examples II and III are, however, not scaled-up versions of the rear member L_D of Example I. The front three members L_A, L_B, L_C of Example IV, which includes yet another alternative construction of rear member L_D, are of the same general type as those of Examples I–III, but their numerical dimensions differ somewhat from a version of those of Example I scaled up in the ratio 4.0/1.6.

All these examples cover a semi-angular field of view varying from 27 degrees at F_o to 2.7 degrees at F_M.

The iris diaphragm in all four examples is stationary and is located between the movable third member L_C and the stationary rear member L_D. In Example I the diaphragm is 0.0625 F_o in front of the surface R_{17} and has diameter 0.8568 F_o; in Example II the diaphragm is 0.0929 F_o in front of the surface R_{17} and has diameter 1.2240 F_o; in Example III the diaphragm is 0.1375 F_o in front of the surface R_{17} and has diameter 1.2240 F_o; and in Example IV the diaphragm is 0.2407 F_o in front of the surface R_{17} and has diameter 2.1446 F_o.

The back focal distance from the rear surface of the objective to the image plane is 2.8301 F_o in Example I, 2.6761 F_o in Example II, 2.3027 F_o in Example III and 1.7878 F_o in Example IV.

The equivalent focal length f_A of the stationary first member L_A is + 4.4551 F_o in Example I, + 6.3644 F_o in Examples II and III and + 11.1413 F_o in Example IV; the equivalent focal length f_B of the movable second member L_B is − 1.4703 F_o in Example I, − 2.1004 F_o in Examples II and III and − 3.6770 F_o in Example IV; the equivalent focal length f_C of the movable third member L_C is − 1.8176 F_o in Example I, − 2.5966 F_o in Examples II and III and − 4.5458 F_o in Example IV; and the equivalent focal length f_D of the stationary fourth member L_D is + 1.4753 F_o in Example I, + 2.1286 F_o in Example II, + 2.3232 F_o in Example III and + 4.0419 F_o in Example IV; the positive and negative signs respectively indicating convergence and divergence.

In all four examples, the convergent stationary front member L_A consists of a meniscus doublet component followed by two convergent simple components. The front surface R_1 of the doublet component is concave to the front and has dispersive optical power numerically equal to 0.155/F_o or 0.692/f_A in Example I, to 0.109/F_o or 0.692/f_A in Examples II and III, and to 0.062/F_o or 0.692/f_A in Example IV. The internal contact R_2 of the doublet component is dispersive and convex to the front and has radius of curvature equal to 2.037 f_A in all four examples. The difference between the mean refractive indices of the materials of the two elements of such doublet component is 0.27 in all four examples.

The combined equivalent focal length of the two simple components of the first member L_A is 4.0013 F_o in Example I, 5.7162 F_o in Examples II and III, and 10.0064 F_o in Example IV or 0.8981 f_A in all four examples. The radius of curvature R_4 of the front surface of the first of such simple components is 2.551 f_A in all four examples, and the radius of curvature R_6 of the front surface of the second of such simple components is 0.880 f_A in all four examples. The rear surface R_7 of such second simple component is convex to the front with radius of curvature 3.852 f_A in all four examples.

The axial thickness $(D_1 + D_2)$ of the meniscus doublet component of the first member L_A is 0.766 F_o in Example I, 1.094 F_o in Examples II and III, and 1.916 F_o in Example IV, or 0.172 f_A in all four examples. The sum of the axial thicknesses of the two simple components $(D_3 + D_4)$ of the first member is 0.553 F_o in Example I, 0.790 F_o in Examples II and III, and 1.383 F_o in Example IV, or 0.124 f_A in all four examples.

The arithmetic mean between the Abbe V numbers of the materials of the three convergent elements of the first member L_A in all four examples is 50.72 and thus exceeds the Abbe V number of the material of the divergent front element by 24.62.

The maximum value of the ratio of the equivalent focal length of the objective to the f-number of the objective is 2.5 F_o in Example I, 3.57 F_o in Examples II and III, and 6.25 F_o in Example IV, so that in all four examples f_A is 1.782 times such maximum value.

In all four examples, the minimum separation between the movable second and third members L_B and L_C occurs when the equivalent focal length of the objective is 7.45 F_o, and the numerical values of the equivalent focal lengths f_B and f_C of such members are respectively 5.88 and 7.27 times the minimum value of the ratio of the equivalent focal length of the objective to the f-number of the objective.

The movable second member L_B in all four examples consists of a divergent simple meniscus component with its surfaces convex to the front followed by a divergent triplet component having a convergent element between two divergent elements, and its total axial movement (a unidirectional rearward movement) in the range of variation is numerically equal to 1.994 f_B. The front and rear surfaces R_8 and R_9 of the simple meniscus component of such member respectively have radii of curvature numerically equal to 1.39 f_B and 0.83 f_B in all four examples, whilst the front and rear surfaces R_{10} and R_{13} of the triplet component respectively have radii of curvature numerically equal to 1.86 f_B in Examples I–III and 1.87 f_B in Example IV and to 3.93 f_B in Examples I–III and 3.99 f_B in Example IV.

The movable third member L_C in all four examples consists of a doublet component, whose front surface R_{14} is concave to the front with radius of curvature numerically equal to 0.72 f_C, and the total axial movement (the numerical sum of an initial forward movement

plus a subsequent rearward movement) of such member is numerically equal to 0.363 f_r. The internal contact R_{32} of such doublet component is collective and convex to the front, with radius of curvature numerically equal to 0.72 f_r. The difference between the mean refractive indices of the materials of such doublet component is 0.087 in Examples I – III and 0.088 in Example IV, the difference between their Abbe V numbers being 30.09 in Examples I – III and 30.24 in Example IV.

In all four examples, the various aberrations are well stabilized in the front three members L_A, L_B, L_C throughout the range of variation of equivalent focal length of the objective and also throughout the focussing range, and the stationary rear member L_D serves to balance out such residual stabilized aberrations, and also to locate the resultant image plane in a convenient position. The construction of such rear member may thus vary widely.

In Examples I and II, such rear member may be described as of modified Cooke triplet construction, wherein the strong convergent power needed at the front to deal with the relatively widely divergent beam received from the third member is achieved by the use of three simple convergent components, which are followed by a simple divergent component and either a convergent doublet component as in Example I or a convergent doublet component followed by a convergent simple component as in Example II. In these two examples an aspheric surface is used in order to assist in balancing out the residual stabilized aberrations of the front three members without undue increase in the overall length of the objective, such aspheric surface being the front surface R_{20} of the simple divergent component, where it can be employed for the simultaneous correction of spherical aberration and coma with minimum effect on oblique aberrations.

In Example III, a somewhat different type of stationary rear member is used, which may be described as of modified Petzval construction. In this case, six simple components are used, the first three again being convergent in order to give the necessary strong convergent power at the front, whilst the next two are divergent and the sixth is convergent. Although no aspheric surface is used in the actual example given, some further improvement in aberration correction could be achieved by incorporating such a surface.

Yet another alternative construction for the stationary rear member L_D is employed in Example IV, consisting of seven simple components, the first three and the last two being convergent, and the fourth and fifth divergent. An aspheric surface is again used, in this case the front surface R_{28} of the rearmost component.

It is often desired in practice to provide two different ranges of variation of the equivalent focal length of the objective, and with the objective according to the present invention this can be carried out in a simple way by the provision of an achromatic doublet component, which can be placed at will behind the stationary rear member L_D of the objective, such doublet component, when in position, acting to move the resultant image plane further from the rear surface of the member L_D and to increase the values of the equivalent focal length of the objective in the same proportion throughout the range. Another effect of the addition of this doublet component is to reduce the relative aperture of the objective and the angular field covered. Numerical data are given below of two alternative examples of achromatic doublet component suited to follow the rear member L_D of Example I above. FIGS. 5 and 6 respectively show these two examples of doublet component L_E in position behind the main objective, which for simplicity is shown only in skeleton form, the front and rear surfaces only being shown for each of the four members L_A, L_B, L_C and L_D of the objective.

EXAMPLE V

Radius	Thickness or air separation	Refractive index n_d	Abbe V number	Clear diameter
	S_{33} = [illegible]			
R_{34} = ∞				R_{34} [illegible]
	D_{34} = [illegible]	[illegible]	[illegible]	
R_{35} = − [illegible]				R_{35} [illegible]
	D_{35} = [illegible]	[illegible]	[illegible]	
R_{36} = + [illegible]				R_{36} [illegible]

EXAMPLE VI

Radius	Thickness or air separation	Refractive index n_d	Abbe V number	Clear diameter
	S_{33} = [illegible]			
R_{34} = ∞				R_{34} [illegible]
	D_{34} = [illegible]	[illegible]	[illegible]	
R_{35} = − [illegible]				R_{35} [illegible]
	D_{35} = [illegible]	[illegible]	[illegible]	
R_{36} = + [illegible]				R_{36} [illegible]

The dimensions in these two examples of achromatic doublet component are given in terms of the minimum value F_o of the equivalent focal length for the objective of Example I. In each table S_{33} represents the air separation between the rear surface R_{33} of the stationary rear member L_D of Example I and the front surface R_{34} of the added doublet component. The doublet component in each case consists of a convergent element in front of a divergent element.

The added doublet component L_E of Example V increases the values of the equivalent focal length in the ratio 3:2, so that the normal range from F_o to 10 F_o is altered by the doublet component into a range from 1.5 F_o to 15 F_o. The doublet component of Example VI acts to double the values of the equivalent focal length of Example I, thus giving a range from 2 F_o to 20 F_o when the doublet component is in position.

The back focal distance from the rear surface R_{36} of the added doublet component L_E to the new position of the resultant image plane is 3.704 F_o in Example V and 4.028 F_o in Example VI. The relative aperture of the objective is changed from f/4.0 by the addition of the doublet component to f/6.0 in Example V and f/8.0 in Example VI. The semi-angular field, which for Example I alone varies from 27 degrees at F_o to 2.7 degrees at F_m, varies (when the doublet component of Example V is added) from 18 degrees at 1.5 F_o to 1.8 degrees at 15 F_o, and (when the doublet component of Example VI is added) from 13.5 degrees at 2 F_o to 1.35 degrees at 20 F_o.

It will be realized that the addition of only an achromatic doublet component to an already well-corrected objective must necessarily result in a lower standard of aberration correction when the doublet component is in place. But the increased equivalent focal length and reduced relative aperture and angular field do not call for so high a standard of correction as is needed when the objective is used alone, and for many practical purposes the standard of correction obtained with the dou-

blet component added is adequate.

The necessary axial movement of the second and third members may be brought about in various ways, for example by means of two appropriately shaped cams, which may be in the form of cam grooves B and E on the outer surface of a tubular member C rotated by the zoom control element G and surrounding the second and third members M and H, which are held against rotation relatively to the fixed casing F of the objective. The focusing movement of the front member P may be effected under the control of a focusing control element O by mounting the front member in screw threaded engagement with the fixed casing F of the objective.

It will be appreciated that the foregoing examples have been given by way of example only and that the invention can be carried into practice in other ways.

We claim:

1. An optical objective of the zoom type (that is of the type having relatively movable members whereby the equivalent focal length of the objective can be continuously varied throughout a range, whilst maintaining constant position of the image plane), corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, said objective having a maximum equivalent focal length at least 6 times its minimum focal length, and comprising a convergent first member which for a given object distance remains stationary during the zooming relative movements, an axially movable divergent second member behind the first member having equivalent focal length f_B lying numerically between 4 and 8 times the minimum value of the ratio of the equivalent focal length of the complete objective to the f-number of the objective in the range of variation, an axially movable divergent third member behind the second member having equivalent focal length f_C lying numerically between 5 and 10 times the minimum value of such ratio, a stationary convergent fourth member behind the third member, a zoom control element, and means whereby operation of the zoom control element causes the zooming relative movements to be effected, wherein the total axial movement of the second member in the range of variation lies numerically between $1.5f_B$ and $2.5f_B$ and the total axial movement of the third member in the range lies numerically between $0.25f_C$ and $0.5f_C$, the minimum axial separation between the second and third member occurring when the equivalent focal length of the objective is greater than half its maximum value in the range of variation, the movable divergent second member consisting of a divergent simple meniscus component with its surfaces convex to the front and a divergent compound component behind such simple component, and the movable divergent third member consisting of a doublet component having its front surface concave to the front.

2. An optical objective as claimed in claim 1, in which the compound component in the divergent movable second member includes at least one convergent element and at least one divergent element made of materials of differing Abbe V numbers.

3. An optical objective as claimed in claim 2, in which the front surface of the compound component of the second member is concave to the front and the rear surface of such component is convex to the front.

4. An optical objective as claimed in claim 3, in which the compound component of the second member consists of a triplet component having a convergent element between two divergent elements.

5. An optical objective as claimed in claim 4, in which the doublet component constituting the third member has a collective internal contact convex to the front.

6. An optical objective as claimed in claim 2, in which the front surface of the compound component of the second member is concave to the front and the rear surface of such component is convex to the front.

7. An optical objective as claimed in claim 2, in which the doublet component constituting the third member has a collective internal contact convex to the front, and the materials of the two elements of such component having differing Abbe V numbers and differing mean refractive indices.

8. An optical objective as claimed in claim 1, in which the front surface of the compound component of the second member is concave to the front and the rear surface of such component is convex to the front.

9. An optical objective as claimed in claim 8, in which the compound component of the second member consists of a triplet component having a convergent element between two divergent elements, the materials of all the elements of the second member having mean refractive indices greater than 1.69 and being such that the arithmetic mean between the Abbe V numbers of the materials of the divergent elements exceeds that of the convergent element.

10. An optical objective as claimed in claim 9, including an achromatic doublet which can be placed at will behind the stationary rear member of the objective and acts when in its operative position to increase the values of the equivalent focal length of the objective by a chosen ratio throughout the range of variation.

11. An optical objective as claimed in claim 1, in which the compound component of the second member consists of a triplet component having a convergent element between two divergent elements.

12. An optical objective as claimed in claim 11, in which the doublet component constituting the third member has a collective internal contact convex to the front with radius of curvature substantially equal to $0.72f_C$, the materials of the two elements of such component having Abbe V numbers which differ by about 30 and mean refractive indices which are each greater than 1.69 and differ by about 0.09.

13. An optical objective as claimed in claim 1, in which the doublet component constituting the divergent movable third member has a collective internal contact convex to the front with radius of curvature substantially equal to $0.72f_C$, the difference between the mean refractive indices of the materials of the two elements of such component being about 0.09, while the difference between the Abbe V numbers of such materials is about 30.

14. An optical objective as claimed in claim 13, including an achromatic doublet which can be placed at will behind the stationary rear member of the objective and acts when in its operative position to increase the values of the equivalent focal length of the objective by a chosen ratio throughout the range of variation.

15. An optical objective of the zoom type (that is of the type having relatively movable members whereby the equivalent focal length of the objective can be continuously varied throughout a range, whilst maintaining

constant position of the image plane), corrected for spherical and chromatic aberrations, coma, astigmatism, field curvature and distortion, and comprising a convergent first member which for a given object distance remains stationary during the zooming relative movements, an axially movable divergent second member behind the first member having equivalent focal length f_B lying numerically between 4 and 8 times the minimum value of the ratio of the equivalent focal length of the complete objective to the f-number of the objective in the range of variation, an axially movable divergent third member behind the second member having equivalent focal length f_C lying numerically between 5 and 10 times the minimum value of such ratio, a stationary convergent fourth member behind the third member, a zoom control element, and means whereby operation of the zoom control causes the zooming relative movements to be effected, wherein the total axial movement of the second member in the range of variation lies numerically between $1.5f_B$ and $2.5f_B$ and the total axial movement of the third member in the range lies numerically between $0.25f_C$ and $0.5f_C$, the minimum axial separation between the second and third members occurring when the equivalent focal length of the objective is greater than half its maximum value in the range of variation, the movable divergent second member consisting of a divergent simple meniscus component with its surfaces convex to the front and a divergent compound component behind such simple component, the movable divergent third member consisting of a doublet component having its front surface concave to the front, and the first member of the objective comprises a meniscus doublet component having a front surface which is concave to the front and two simple convergent components behind such meniscus doublet component.

16. An optical objective as claimed in claim 15, in which the internal contact of the meniscus doublet component of the first member is dispersive and convex to the front.

17. An optical objective as claimed in claim 16, in which the compound component in the divergent movable second member includes at least one convergent element and at least one divergent element, and the doublet component constituting the third member has a collective internal contact convex to the front.

18. An optical objective as claimed in claim 15, in which the two simple components of the first member together have their front surfaces convex to the front, the radius of curvature of the front surface of the first of such simple components being greater than twice the radius of curvature of the front surface of the second of such simple components, the rear surface of the second of the two simple components being convex to the front.

19. An optical objective as claimed in claim 15, in which the axial thickness of the meniscus doublet component of the first member is is greater than the sum of the axial thicknesses of the two simple components of the first member.

20. An optical objective as claimed in claim 19, including an achromatic doublet which can be placed at will behind the stationary rear member of the objective, and acts when in its operative position to increase the values of the equivalent focal length of the objective by a chosen ratio throughout the range of variation.

21. An optical objective as claimed in claim 15, including an achromatic doublet which can be placed at will behind the stationary rear member of the objective and acts when in its operative position to increase the values of the equivalent focal length of the objective by a chosen ratio throughout the range of variation.

22. An optical objective as claimed in claim 21, in which the internal contact of the meniscus doublet component of the first member is dispersive and convex to the front with radius of curvature substantially equal to $2.64f_A$, the difference between the mean refractive indices of the materials of the two elements of the doublet being substantially 0.27.

* * * * *

UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,736,048 Dated May 29, 1973

Inventor(s) GORDON HENRY COOK and PETER ARNOLD MERIGOLD

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

[73] Assignee: The Rank Organisation Limited
London, England

[30] Foreign Application Priority Data
Sept. 14, 1962 Great Britain..........35088

Signed and sealed this 27th day of November 1973.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

RENE D. TEGTMEYER
Acting Commissioner of Patents